

VOLUME VIII: Introduction

INTRODUCTION TO ESTIMATING GREENHOUSE GAS EMISSIONS

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DISCLAIMER

As the Environmental Protection Agency has indicated in Emission Inventory Improvement Program (EIIP) documents, the choice of methods to be used to estimate emissions depends on how the estimates will be used and the degree of accuracy required. Methods using site-specific data are preferred over other methods. These documents are non-binding guidance and not rules. EPA, the States, and others retain the discretion to employ or to require other approaches that meet the requirements of the applicable statutory or regulatory requirements in individual circumstances.

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BACKGROUND AND OBJECTIVES

The objective of the Emission Inventory Improvement Program (EIIP) is to facilitate the development of cost-effective, reliable inventories of air pollutant emissions by (1) improving the quality of emissions information, and (2) developing systems for collecting, calculating, and reporting emissions data. Toward this end, EIIP has published a series of volumes designed to help states estimate emissions of various air pollutants. The purpose of Volume VIII is to present emissions estimation techniques for greenhouse gas sources and sinks in a clear and unambiguous manner and to provide concise example calculations to aid in the preparation of emission inventories. Compiling an inventory of greenhouse gas emissions is a critical first step toward developing policies and strategies to mitigate greenhouse gas emissions.

This volume offers basic approaches to conducting a greenhouse gas emissions inventory and, in some cases, offers more complex approaches as well; a state may select approaches based on the resources available and the level of effort the state can undertake. Unlike the pollutants covered by other volumes in this series, the emission estimates for greenhouse gases are not required as part of a regulatory program, and thus there is considerable flexibility in choosing methods.

This volume is based largely on the U.S. Environmental Protection Agency report *State Workbook: Methodologies for Estimating Greenhouse Gas Emissions*. (U.S. EPA 1998a). It expands on the *State Workbook* by (1) adding two chapters that were not included in the *State Workbook* (Chapters 13 and 14, which cover, respectively, non-CO₂ emissions from mobile sources and stationary sources),

Methodological Advances in GHG Inventories

Methods for developing greenhouse gas inventories are continuously evolving and improving. The methods presented in this report represent the work of the EIIP Greenhouse Gas Committee over a several month period in 1998 and early 1999. This volume takes into account the guidance and information available at the time on inventory methods, specifically, U.S. EPA's *State Workbook: Methodologies for Estimating Greenhouse Gas Emissions* (U.S.EPA 1998a), volumes 1-3 of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1997) and the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 1996* (U.S. EPA 1998b).

There have been several recent developments in inventory methodologies, including:

- Publication of EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 1997* (U.S. EPA 1999) and completion of the draft inventory for 1990 – 1998. These documents will include methodological improvements for several sources, and present the U.S. methodologies in a more transparent manner than previous inventories;
- Initiation of several new programs with industry, which are providing new data and information that can be applied to current methods or applied to more accurate and reliable methods (so called "higher tier methods" by IPCC); and
- The IPCC Greenhouse Gas Inventory Program's upcoming report on Good Practice in Inventory Management, which develops good practice guidance for the implementation of the 1996 IPCC Guidelines. The report will be published by the IPCC in May 2000.

Note that the EIIP Greenhouse Gas Committee has not incorporated these developments into this version of the volume. Given the rapid pace of change in the area of greenhouse gas inventory methodologies, users of this document are encouraged to seek the most up-to-date information from EPA and the IPCC when developing inventories.

and (2) including tables which evaluate the accuracy of emission factors and activity levels used to estimate greenhouse gas emissions (these tables are known as “Data Attribute Ranking System” or DARS tables). This volume also reflects (1) a number of methodologic improvements suggested by state energy and environmental officials on the Greenhouse Gas Committee of the EIIP, (2) recent methods adopted in the course of developing the *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-1996* (U.S. EPA 1998b), and (3) the methods recommended in the guidelines for national greenhouse gas inventories published by the Intergovernmental Panel on Climate Change (IPCC 1997).

The balance of this chapter covers the following topics:

- Introduction to greenhouse gases and climate change,
- International and national activities on greenhouse gas emissions,
- State greenhouse gas inventories and action plans to mitigate greenhouse gas emissions,
- Preparing a state-level greenhouse gas inventory,
- Harmonizing state, national, and international inventory methods,
- Overview of Volume VIII, and
- References.

INTRODUCTION TO GREENHOUSE GASES AND CLIMATE CHANGE

The Greenhouse Effect (Natural and Anthropogenic)

The Earth naturally absorbs and reflects incoming solar radiation and emits longer wavelength terrestrial (thermal) radiation back into space. On average, the absorbed solar radiation is balanced by the outgoing terrestrial radiation emitted to space. A portion of this terrestrial radiation, though, is itself absorbed by gases in the atmosphere. The energy from this absorbed terrestrial radiation warms the Earth's surface and atmosphere, creating what is known as the “natural greenhouse effect.” Without the natural heat-trapping properties of these atmospheric gases, the average surface temperature of the Earth would be about 34° C lower (IPCC 1996). Although the Earth's atmosphere consists mainly of oxygen and nitrogen, neither play a significant role in this greenhouse effect because both are essentially transparent to terrestrial radiation. The greenhouse effect is primarily a function of the concentration of water vapor, carbon dioxide, and other trace gases in the atmosphere that absorb the terrestrial radiation leaving the surface of the Earth (IPCC 1996). Changes in the atmospheric concentrations of these greenhouse gases can alter the balance of energy transfers between the atmosphere, space, land, and the oceans. A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth-atmosphere system (IPCC 1996). Holding everything else constant, increases in greenhouse gas concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the Earth).

The Scientific Consensus Regarding Climate Change

Under the United Nations Framework Convention on Climate Change (FCCC), the definition of climate change is “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods” (UNEP/WMO). Given that definition, in its 1995 assessment of the science of climate change, the IPCC determined that:

Human activities are changing the atmospheric concentrations and distributions of greenhouse gases and aerosols. These changes can produce a radiative forcing by changing either the reflection or absorption of solar radiation, or the emission and absorption of terrestrial radiation (IPCC 1996).

The IPCC went on to report in its scientific assessment that the “[g]lobal mean surface temperature [of the Earth] has increased by between about 0.3 and 0.6 °C since the late 19th century...” (IPCC 1996) and concluded that:

Our ability to quantify the human influence on global climate is currently limited because the expected signal is still emerging from the noise of natural variability, and because there are uncertainties in key factors. These include the magnitude and patterns of long term natural variability and the time-evolving pattern of forcing by, and response to, changes in concentrations of greenhouse gases and aerosols, and land surface changes. Nevertheless, the balance of the evidence suggests that there is a discernable human influence on global climate (IPCC 1996).

Greenhouse Gases, Their Major Sources, and Atmospheric Concentrations

Naturally occurring greenhouse gases include water vapor, carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and ozone (O₃). Several classes of halogenated substances that contain fluorine, chlorine, or bromine are also greenhouse gases, but they are, for the most part, emitted solely by human activities. Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are halocarbons that contain chlorine, while halocarbons that contain bromine are referred to as halons. Other fluorine-containing halogenated substances include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆). There are also several gases that, although they do not have a direct radiative forcing effect, do influence the formation and destruction of ozone, which does have such a terrestrial radiation absorbing effect. These gases-referred to here as ozone precursors-include carbon monoxide (CO), oxides of nitrogen (NO_x), and nonmethane volatile organic compounds (NMVOCs). Aerosols-extremely small particles or liquid droplets emitted directly or produced as a result of atmospheric reactions-can also affect the absorptive characteristics of the atmosphere.

Carbon dioxide, methane, and nitrous oxide are continuously emitted to and removed from the atmosphere by natural processes on Earth. Anthropogenic activities, however, can cause additional quantities of these and other greenhouse gases to be emitted or sequestered,¹ thereby changing their global average atmospheric concentrations. Natural activities such as respiration by plants or animals and seasonal cycles of plant growth and decay are examples of processes that only cycle carbon or nitrogen between the atmosphere and organic biomass. Such processes-except when directly or indirectly perturbed out of equilibrium by anthropogenic activities-generally do not alter average atmospheric greenhouse gas concentrations over decadal timeframes. Climatic changes resulting from anthropogenic activities, however, could have positive or negative feedback effects on these natural systems.

A brief description of each greenhouse gas, its sources, and its role in the atmosphere is given below. The following section then explains the concept of Global Warming Potentials (GWPs), which are assigned to individual gases as a measure of their relative average global radiative forcing effect.

Water Vapor (H₂O). Overall, the most abundant and dominant greenhouse gas in the atmosphere is water vapor. Water vapor is neither long-lived nor well-mixed in the atmosphere, varying spatially from 0 to 2 percent (IPCC 1996). In addition, atmospheric water can exist in several

¹ Carbon from carbon dioxide is sequestered when it is removed from the atmosphere for a long time period. For example, forests sequester carbon in trees.

physical states including gaseous, liquid, and solid. Human activities are not believed to directly affect the average global concentration of water vapor; however, the radiative forcing produced by the increased concentrations of other greenhouse gases may indirectly affect the hydrologic cycle. A warmer atmosphere has an increased water holding capacity; yet, increased concentrations of water vapor affect the formation of clouds, which can both absorb and reflect solar and terrestrial radiation.

Carbon Dioxide (CO₂). In nature, carbon is cycled between various atmospheric, oceanic, land biotic, marine biotic, and mineral reservoirs. The largest fluxes occur between the atmosphere and terrestrial biota, and between the atmosphere and surface water of the oceans. In the atmosphere, carbon predominantly exists in its oxidized form as CO₂. Atmospheric carbon dioxide is part of this global carbon cycle, and therefore its fate is a complex function of geochemical and biological processes. Carbon dioxide concentrations in the atmosphere, as of 1994, increased from approximately 280 parts per million by volume (ppmv) in pre-industrial² times to 358 ppmv, a more than 25 percent increase (IPCC 1996).³ The IPCC has stated that “[t]here is no doubt that this increase is largely due to human activities, in particular fossil fuel combustion...” (IPCC 1996). Forest clearing, other biomass burning, and some non-energy production processes (e.g., cement production) also emit notable quantities of carbon dioxide.

In its latest scientific assessment, the IPCC also stated that “[t]he increased amount of carbon dioxide [in the atmosphere] is leading to climate change and will produce, on average, a global warming of the Earth’s surface because of its enhanced greenhouse effect-although the magnitude and significance of the effects are not fully resolved” (IPCC 1996).

Methane (CH₄). Methane is produced through anaerobic decomposition of organic matter in biological systems. Agricultural processes such as wetland rice cultivation, enteric fermentation in animals, and the decomposition of animal wastes emit CH₄, as does the decomposition of municipal solid wastes. Methane is also emitted during the production and distribution of natural gas and petroleum, and is released as a by-product of coal mining and incomplete fossil fuel combustion. The average global concentration of methane in the atmosphere was 1,720 parts per billion by volume (ppbv) in 1994, a 145 percent increase from the pre-industrial concentration of 700 ppbv (IPCC 1996). It is estimated that 60 to 80 percent of current CH₄ emissions are the result of anthropogenic activities. Carbon isotope measurements indicate that roughly 20 percent of methane emissions are from fossil fuel consumption, and an equal percentage is produced by natural wetlands, which will likely increase with rising temperatures and rising microbial action (IPCC 1996).

Methane is removed from the atmosphere by reacting with the hydroxyl radical (OH⁻) and is ultimately converted to CO₂. Increasing emissions of methane, though, reduce the concentration of OH⁻, and thereby the rate of further methane removal (IPCC 1996).

² The pre-industrial period is defined as the time preceding the year 1750 (IPCC 1996).

³ Carbon dioxide concentrations during the last 100 years of the pre-industrial period (1650-1750), a time of relative climate stability, fluctuated by about ± 10 ppmv around 280 ppmv (IPCC 1996).

Nitrous Oxide (N₂O). Anthropogenic sources of N₂O emissions include agricultural soils, especially the use of synthetic and manure fertilizers; fossil fuel combustion, especially from mobile sources; adipic (nylon) and nitric acid production; wastewater treatment and waste combustion; and biomass burning. The atmospheric concentration of nitrous oxide (N₂O) in 1994 was about 312 parts per billion by volume (ppbv), while pre-industrial concentrations were roughly 275 ppbv. The majority of this 13 percent increase has occurred after the pre-industrial period and is most likely due to anthropogenic activities (IPCC 1996). Nitrous oxide is removed from the atmosphere primarily by the photolytic action of sunlight in the stratosphere.

Ozone (O₃). Ozone is present in both the stratosphere,⁴ where it shields the Earth from harmful levels of ultraviolet radiation, and at lower concentrations in the troposphere⁵, where it is the main component of anthropogenic photochemical “smog”. During the last two decades, emissions of anthropogenic chlorine and bromine-containing halocarbons, such as chlorofluorocarbons (CFCs), have depleted stratospheric ozone concentrations. This loss of ozone in the stratosphere has resulted in negative radiative forcing, representing an indirect effect of anthropogenic emissions of chlorine and bromine compounds (IPCC 1996). Ozone in the troposphere has increased dramatically in the past 100 years, contributing to increased radiative forcing.

Tropospheric ozone, which is also a greenhouse gas, is produced from the oxidation of methane and from reactions with precursor gases such as carbon monoxide (CO), nitrogen oxides (NO_x), and non-methane volatile organic compounds (NMVOCs). This latter group of ozone precursors are included in the category referred to as “criteria pollutants” in the United States under the Clean Air Act⁶ and its subsequent amendments. The tropospheric concentrations of both ozone and these precursor gases are short-lived and, therefore, spatially variable.

Halocarbons. Halocarbons are for the most part man-made chemicals that have both direct and indirect radiative forcing effects. Halocarbons that contain chlorine (i.e., chlorofluorocarbons, or CFCs, hydrochlorofluorocarbons, or HCFCs, methyl chloroform, and carbon tetrachloride) or bromine (i.e., halons and methyl bromide) result in stratospheric ozone depletion and are therefore controlled under the *Montreal Protocol on Substances that Deplete the Ozone Layer*. Although some CFCs and HCFCs are potent global warming gases, their net radiative forcing effect on the atmosphere is reduced because they cause stratospheric ozone depletion, which is itself an important greenhouse gas in addition to shielding the Earth from harmful levels of ultraviolet radiation. Under the *Montreal Protocol*, the United States phased out production and importing of halons by 1994 and of CFCs by 1996. Under the Copenhagen Amendments to the

⁴ The stratosphere is the layer from the troposphere up to roughly 50 kilometers. In the lower regions the temperature is nearly constant but in the upper layer the temperature increases rapidly because of sunlight absorption by the ozone layer. The ozone layer is the part of the stratosphere from 19 kilometers up to 48 kilometers where the concentration of ozone reaches up to 10 parts per million.

⁵ The troposphere is the layer from the ground up to 11 kilometers near the poles and up to 16 kilometers in equatorial regions (i.e., the lowest layer of the atmosphere where people live). It contains roughly 80 percent of the mass of all gases in the atmosphere and is the site for most weather processes, including most of the water vapor and clouds.

⁶ [42 U.S.C § 7408, CAA § 108]

Protocol, a cap was placed on the production and importation of HCFCs by non-Article 5⁷ countries beginning in 1996, and then followed by a complete phase-out by the year 2030. The ozone depleting gases covered under the *Montreal Protocol* and its Amendments are not covered by the FCCC.

Perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), and sulfur hexafluoride (SF₆) are not ozone depleting substances, and therefore are not covered under the *Montreal Protocol*. They are, however, powerful greenhouse gases. HFCs—primarily used as replacements for ozone depleting substances but also emitted as a by-product of the HCFC-22 manufacturing process—currently have a small aggregate radiative forcing impact; however, it is anticipated that their contribution to overall radiative forcing will increase (IPCC 1996). PFCs and SF₆ are predominantly emitted from various industrial processes including aluminum smelting, semiconductor manufacturing, electric power transmission and distribution, and magnesium casting. Currently, the radiative forcing impact of PFCs and SF₆ is also small; however, because these gases have extremely long atmospheric lifetimes, their concentrations tend to irreversibly accumulate in the atmosphere.

Carbon Monoxide (CO). Carbon monoxide has an indirect radiative forcing effect by elevating concentrations of CH₄ and tropospheric ozone through chemical reactions with other atmospheric constituents (e.g., the hydroxyl radical) that would otherwise assist in destroying CH₄ and tropospheric ozone. Carbon monoxide is created when carbon-containing fuels are burned incompletely. Through natural processes in the atmosphere, it is eventually oxidized to CO₂. Carbon monoxide concentrations are both short-lived in the atmosphere and spatially variable.

Nitrogen Oxides (NO_x). The primary climate change effects of nitrogen oxides (i.e., NO and NO₂) are indirect and result from their role in promoting the formation of tropospheric ozone and, to a lesser degree, lower stratospheric ozone. (NO_x emissions injected higher in the stratosphere⁸ can lead to stratospheric ozone depletion.). Nitrogen oxides are created from lightning, soil microbial activity, biomass burning (both natural and anthropogenic fires), fossil fuel combustion, and, in the stratosphere, from nitrous oxide (N₂O). NO_x is relatively short-lived in the atmosphere and its concentrations are spatially variable.

Nonmethane Volatile Organic Compounds (NMVOCs). Nonmethane volatile organic compounds include compounds such as propane, butane, and ethane. These compounds participate, along with NO_x, in the formation of tropospheric ozone and other photochemical oxidants. NMVOCs are emitted primarily from transportation and industrial processes, as well as biomass burning and non-industrial consumption of organic solvents. NMVOCs tend to be short-lived in the atmosphere and their concentrations are spatially variable.

⁷ Article 5 of the *Montreal Protocol* covers several groups of countries, especially developing countries, with low consumption rates of ozone depleting substances. Developing countries with per capita consumption of less than 0.3 kg receive financial assistance and a grace period of ten additional years in the phase-out of ozone depleting substances.

⁸ Primarily from fuel combustion emissions from high altitude aircraft.

Aerosols. Aerosols are extremely small particles or liquid droplets found in the atmosphere. They can be produced by natural events such as dust storms and volcanic activity or by anthropogenic processes such as fuel combustion. Their effect upon radiative forcing is to both absorb radiation and to alter cloud formation, thereby affecting the reflectivity (i.e., albedo) of the Earth. Aerosols are removed from the atmosphere primarily by precipitation, and generally have short atmospheric lifetimes. Like ozone precursors, aerosol concentrations and composition vary by region (IPCC 1996).

Anthropogenic aerosols in the troposphere are primarily the result of sulfur dioxide (SO₂)⁹ emissions from fossil fuel and biomass burning. Overall, aerosols tend to produce a negative radiative forcing effect (i.e., a net cooling effect on the climate). Because they are short-lived in the atmosphere—lasting days to weeks—their concentrations respond rapidly to changes in emissions.¹⁰ Locally, the negative radiative forcing effects of aerosols can offset the positive forcing of greenhouse gases (IPCC 1996). “However, the aerosol effects do not cancel the global-scale effects of the much longer-lived greenhouse gases, and significant climate changes can still result” (IPCC 1996).

Global Warming Potentials of Greenhouse Gases

The Global Warming Potential (GWP) is a measure that quantifies the relative radiative forcing impacts of various greenhouse gases. It is defined as the cumulative radiative forcing—both direct and indirect effects—over a specified time horizon resulting from the emission of a unit mass of gas relative to some reference gas (IPCC 1996). Direct effects occur when the gas itself is a greenhouse gas. Indirect radiative forcing occurs when chemical transformations involving the original gas produce a gas or gases that are greenhouse gases, or when a gas influences the atmospheric lifetimes of other gases. The reference gas used is CO₂. GWP-weighted emissions are expressed in metric tons of carbon equivalent (MTCE). Carbon comprises 12/44ths of carbon dioxide by weight. In order to convert emissions reported in metric tons (MT) of a gas to MTCE, the following equation is used:

$$\text{MTCE} = (\text{MT of gas}) \times (\text{GWP}) \times \left(\frac{12}{44} \right)$$

where,

MTCE = Metric Tons of Carbon Equivalent

GWP = Global Warming Potential

$\left(\frac{12}{44} \right)$ = Ratio of mass of carbon to mass of carbon dioxide

⁹ Sulfur dioxide is a primary anthropogenic contributor to the formation of “acid rain” and other forms of atmospheric acid deposition.

¹⁰ Volcanic activity can inject significant quantities of aerosol producing sulfur dioxide and other sulfur compounds into the stratosphere, which can result in a longer negative forcing effect (i.e., a few years) (IPCC 1996).

GWP values allow policy makers to compare the impacts of emissions and reductions of different gases. According to the IPCC, GWPs typically have an uncertainty of ± 35 percent. The parties to the FCCC have also agreed to use GWPs based upon a 100 year time horizon although other time horizon values are available. Global warming potentials and atmospheric lifetimes for greenhouse gases are shown in Table I.2-1.

Greenhouse gases with long atmospheric lifetimes (e.g., CO₂, CH₄, N₂O, HFCs, PFCs, and SF₆) tend to be evenly distributed throughout the atmosphere, and consequently global average concentrations can be determined. On the other hand, concentrations vary regionally for the short-lived gases such as water vapor, tropospheric ozone, ozone precursors (e.g., NO_x, CO, and NMVOCs), and tropospheric aerosols (e.g., SO₂ products). Consequently, it is difficult to quantify the global radiative forcing impacts of these short-lived gases. No GWP values are attributed to gases that are short-lived with spatially heterogeneous atmospheric concentrations. Other greenhouse gases not yet listed by the Intergovernmental Panel on Climate Change (IPCC), but that are used commercially or soon will be, include HFC-245fa, hydrofluoroethers (HFEs), and nitrogen trifluoride (NF₃).

**Table I.2-1: Global Warming Potentials
and Atmospheric Lifetimes (Years)**

Gas	Atmospheric Lifetime	GWP^a
Carbon dioxide (CO ₂)	50-200	1
Methane (CH ₄) ^b	12 \pm 3	21
Nitrous oxide (N ₂ O)	120	310
HFC-23	264	11,700
HFC-125	32.6	2,800
HFC-134a	14.6	1,300
HFC-143a	48.3	3,800
HFC-152a	1.5	140
HFC-227ea	36.5	2,900
HFC-236fa	209	6,300
HFC-4310mee	17.1	1,300
CF ₄	50,000	6,500
C ₂ F ₆	10,000	9,200
C ₄ F ₁₀	2,600	7,000
C ₆ F ₁₄	3,200	7,400
SF ₆	3,200	23,900

Source: (IPCC 1996)

^a 100 year time horizon

^b The methane GWP includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO₂ is not included.

To stabilize atmospheric concentrations of these gases, substantial cuts in greenhouse gas emissions would be required, perhaps combined with efforts to sequester carbon in forests, soils, and oceans. Because greenhouse gases, once emitted, remain in the atmosphere for decades to centuries, merely stabilizing emissions at current levels would allow the greenhouse effect to continue to intensify. For example, to stabilize the atmospheric concentration of carbon dioxide, emissions of carbon dioxide might have to be reduced by 50 to 80 percent. While it is not possible to stabilize greenhouse gas concentrations immediately, prompt implementation of measures to reduce emissions would decrease the risk of global warming, and would make stabilization of greenhouse gas concentrations easier in the long run (Lashof and Tirpak, 1990).

INTERNATIONAL AND NATIONAL ACTIVITIES ON GREENHOUSE GAS EMISSIONS

Scientific consensus that the threat of climate change is real has prompted action by governments at the international, national, and state levels. For example, since the mid-1980s, the U.S. has taken an active role in fostering international cooperation and furthering research into the causes and impacts of climate change. Initially, the U.S. worked with technical experts from over 50 countries and the Organization for Economic Cooperation and Development (OECD) to develop methods for estimating greenhouse gas emissions and sinks. This cooperative effort supported the work of the IPCC, a committee jointly established by the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO) in 1988 to assess scientific information related to climate change issues.

In June of 1992, the U.S. further demonstrated its concern about climate change by joining with 154 other nations at the United Nations Conference on Environment and Development in signing the FCCC. Later, in October of 1992, the U.S. became the first industrialized nation to ratify the FCCC Treaty, which came into force on March 21, 1994. The FCCC commits signatories to stabilizing anthropogenic greenhouse gas emissions to “levels that would prevent dangerous anthropogenic interference with the climate system.” To facilitate this, Article 4-1 requires that all parties to the FCCC develop, periodically update, and make available to the Conference of the Parties, national inventories of anthropogenic emissions of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies.

Over a period of several years following formation of the IPCC, the IPCC’s Working Group 1—composed of nearly 140 scientists and national experts from more than 30 countries—worked to produce a set of internationally accepted methods for conducting national emission inventories. The most recent methods have been published as the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Vols. 1-3* (IPCC, 1997). The *Revised 1996 IPCC Guidelines* were accepted by the IPCC at its Twelfth Session (Mexico City, 11-13 September 1996).

In December of 1997, the U.S. met with the other Parties to the FCCC in Kyoto, Japan, where the Parties agreed to an historic protocol to reduce global greenhouse gas emissions and set binding targets for the industrial nations. The emissions target for the U.S. is 7 percent below 1990 emissions levels. The Kyoto Protocol reflects many of the proposals advanced in Kyoto by the U.S., including international emissions trading, the inclusion of all six major greenhouse gases (CO₂, CH₄, N₂O, HFCs, PFCs, and SF₆) in emissions targets, and a budget period of 2008-2012 for achieving targets.

The Parties to the FCCC met again in Buenos Aires in November 1998, where they set a deadline—the end of the year 2000—for establishing rules for enforcing the Kyoto Protocol. The

rules are to include measures to prevent cheating and penalize non-compliance, and guidelines for market mechanisms such as emissions trading. During the Buenos Aires conference, the United States signed the Kyoto Protocol, but Clinton Administration officials said the Administration would not submit the Protocol to the Senate for ratification until developing countries were included. Also during the conference, Argentina and Kazakhstan, two developing countries, announced they would voluntarily “opt in” to the Kyoto Protocol. Soon thereafter, more than a dozen other developing countries expressed interest in making some type of commitment to reduce their greenhouse gas emissions.

At the national level, to fulfill its obligation under the FCCC, the U.S. government has published annual greenhouse gas inventories—most recently the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1996* (U.S. EPA, 1998b)¹¹. This series of inventories has tracked the emissions of each greenhouse gas, by source, and provides a benchmark for efforts to reduce emissions. The methods developed and applied in these inventories comply with the IPCC guidelines, but are tailored to U.S. data and conditions. As such, they form the foundation for many of the methods described in this volume.

In 1993, the Clinton Administration developed and published the *Climate Change Action Plan* (CCAP; Clinton and Gore, 1993) to assist the U.S. in meeting its obligation, under the FCCC, to return greenhouse gas emissions to 1990 levels by the year 2000. The *Climate Change Action Plan* promotes the development and expansion of approximately 50 initiatives that span all sectors of the economy and focus on reducing emissions of greenhouse gases in a cost-effective manner. These initiatives call for cooperation between government, industry, and the public. Since they are primarily voluntary in nature, they are designed for rapid implementation. Also, the Department of Energy has released a set of draft guidelines for entities to voluntarily report their reductions of greenhouse gas emissions and sequestration of carbon, achieved through any measure. The purposes of these guidelines are to (1) provide a database of information for entities seeking to reduce their greenhouse gas emissions; (2) establish a formal record of emissions and emission reductions, and carbon sequestration achievements; and (3) inform the public debate in future discussions on national greenhouse gas policy. In 1997, the U.S. government has published the *U.S. Climate Action Report* (U.S. Government, 1997).¹² More recently, STAPPA/ALAPCO (State and Territorial Air Pollution Program Administrators/ Association of Local Air Pollution Control Officials) has been developing a set of greenhouse gas mitigation options as part of their work on “Reducing Emissions of Greenhouse Gases and Air Pollutants: A Harmonized Approach” (STAPPA/ALAPCO, 1998).

At the state level, the U.S. EPA's State and Local Climate Change Program has been working with states to assist them in (1) identifying their greenhouse gas emission sources and estimating

¹¹ Note that EPA published its 1990 – 1997 inventory in April 1999, and will be releasing the 1990 – 1998 inventory in April 2000. Users are encouraged to review these documents for methodological advances.

¹² The *Climate Action Report* represents the U.S. communication under the FCCC as required by Article 4.2 and Article 12. It is a description of the current U.S. program. It does not seek to identify additional policies or measures that might ultimately be taken as the U.S. continues to move forward in addressing climate change, nor does it revise the *Climate Change Action Plan*. It is intended to identify existing policies and measures, and thus to assist in establishing a basis for considering future actions.

their overall greenhouse gas emissions, (2) assessing the areas of the state that are most vulnerable to climate change, and (3) developing state-specific greenhouse gas mitigation strategies. In November of 1992, EPA published the original predecessor to this volume—*State Workbook: Methodologies for Estimating Greenhouse Gas Emissions* (U.S. EPA, 1992). Since then, EPA published the second and third editions of the *Workbook*. EPA also published the *States Guidance Document: Policy Planning to Reduce Greenhouse Gas Emissions* (U.S. EPA 1995). In addition, the National Governors' Association Task Force on Global Warming has proposed more than 20 strategies, consistent with international goals, for responding to the threat of global warming (NGA, 1991). Also, the Council of State Governments' Global Climate Change Task Force has published a plan that recommends 30 ways for Northeastern states to reduce emissions of greenhouse gases (Environmental Information Networks, Inc., 1994).

STATE GREENHOUSE GAS INVENTORIES AND ACTION PLANS

Action at the state and local level is a key component of the U.S. and global response to stabilizing atmospheric concentrations of greenhouse gases, and thus limiting the potential impacts of climate change. For a state that wants to limit its greenhouse gas emissions, the logical first step is to prepare a state-level greenhouse gas inventory. The greenhouse gas inventory will show which emission sources account for the most significant portions of the state's overall greenhouse gas emissions. Based on that knowledge, a state may develop an action plan (i.e., policies and programs) to reduce emissions in those sectors where the potential for reductions is greatest, and the costs are lowest. Many states have already prepared greenhouse gas emission inventories and action plans. Many also have begun to implement programs and policies that are resulting in significant greenhouse gas emission reductions. Table I.4-1 lists the 36 states and one territory that had greenhouse gas inventories completed or underway as of March 1999. In addition, three states are developing state greenhouse gas inventories: Connecticut, Louisiana, and Rhode Island. Twenty-six of the states with completed inventories have begun or completed action plans that identify cost-effective options for reducing greenhouse gas emissions.

Table I.4-1
States and Territories that Had Greenhouse Gas Inventories Completed
or Underway As of March 1999

Alabama	Maryland	Oregon
California	Massachusetts	Pennsylvania
Colorado	Minnesota	Rhode Island
Connecticut	Mississippi	Tennessee
Delaware	Missouri	Texas
Georgia	Montana	Utah
Hawaii	Nevada	Vermont
Illinois	New Hampshire	Virginia
Indiana	New Jersey	Washington
Iowa	New Mexico	Wisconsin
Kansas	New York	
Kentucky	North Carolina	
Maine	Ohio	Puerto Rico

To develop climate change action plans to reduce emissions of greenhouse gases while maintaining economic growth and development, states consider a variety of issues, ranging from the reduction of energy use to reforestation, and from the recycling of wastes to mass transit. Many states have already begun to address these issues. Examples include:

- a California law calling for the California Energy Commission to study the potential impact of climate change on the state's energy supply and demand, the economy, the environment, and agricultural and water resources;
- a Connecticut law establishing a broad range of energy conservation measures;
- Minnesota's adoption of more stringent energy efficiency standards and the initiation of an energy efficiency program focused on the reduction of CO₂ emissions (run by the Energy Division of the Minnesota Department of Public Service);
- New Jersey's commitment to reduce greenhouse gas emissions to 3.5 percent below 1990 levels by 2005, and to establish an in-state greenhouse gas credit bank for early reductions;
- Vermont's energy efficiency standards for new residential construction (developed in cooperation with the building trades, construction industry, and lenders); and
- Requirements in Oregon and Massachusetts that new power plants offset part of their CO₂ emissions.

For more information on these and other state actions to reduce greenhouse gas emissions, visit EPA's global warming web site at <http://www.epa.gov/globalwarming/actions/state/>. This site also houses EPA's guidance document on how to prepare a state action plan (*States Guidance Document: Policy Planning To Reduce Greenhouse Gas Emissions, Second Edition*, U.S. EPA, 1998c).

Many states emit greenhouse gases in amounts comparable to some of the highest emitting countries in the world, whether measured on the basis of total or per-capita emissions. Although problems such as global warming need to be addressed through cooperative national and international efforts, many of the critical responses can be initiated locally. If the adverse effects of climate change are to be avoided, states will need to take an active and immediate role in addressing greenhouse gas emissions. Following are some of the major reasons that states may wish to take action to reduce greenhouse gas emissions:

- States retain much of the policy jurisdiction over emission sources. States have the power to significantly influence greenhouse gas emissions through their influence and authority over energy use, land use, transportation, taxation, environmental programs, and other relevant policy areas.
- The Climate Change Action Plan creates new opportunities for states. These programs provide technical assistance to reduce emissions cost-effectively.
- If emission trading systems are developed, states may be important actors in those systems.
- States have the capacity for enacting "low risk" policies to address climate change. For example, investments in energy efficiency will not only reduce greenhouse gas

emissions, but will also lower energy bills of state residents and reduce emissions of criteria air pollutants.

- States will feel the impacts of climate change and will likely be called upon to address them. State governments may face public and political pressure to respond to climate change.

For a more complete discussion of this topic, see the *States Guidance Document* (U.S. EPA 1998c)

PREPARING A STATE-LEVEL GREENHOUSE GAS INVENTORY

Before a state can effectively develop policies to reduce greenhouse gas emissions and respond to climate change, it needs to identify its anthropogenic greenhouse gas emission sources, and estimate the contribution of these emission sources to overall radiative forcing. This volume presents methodologies to assist states in identifying and estimating their greenhouse gas emissions. These methodologies have been adapted from Volumes 1-3 of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1997) and the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1996* (U.S. EPA, 1998b). Methods for developing greenhouse gas inventories are continuously evolving and improving, and there have been many recent developments in inventory methodologies and other important efforts are underway. Developments include publication of EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 1997* (U.S. EPA 1999), initiation of several new programs with industry, and preparation of the IPCC Greenhouse Gas Inventory Program's upcoming report on Good Practice in Inventory Management, which will be published in May 2000. Given the rapid pace of development in the area of greenhouse gas inventory methodologies, users of this document are encouraged to seek the most up-to-date information from EPA as well as the IPCC when initiating inventory activities.

It is suggested, however, that if a state has access to state- or region-specific emissions factors, or has the ability to take on-site emission measurements at various sources, then the state should consider pursuing these options. Note also that the greenhouse gas inventory methods presented in this volume typically call for the use of “top down” rather than “bottom up” data. For example, CO₂ emissions from gasoline combustion are estimated using data on state-level gasoline consumption (i.e., “top down” data) rather than data on the number and types of motor vehicles in the state, and the average gasoline consumption for each type of vehicle (i.e., “bottom up” data). Where the state has data that would permit the use of a bottom-up greenhouse gas emissions estimate for a given category of sources, the state may choose to use that data, in order to gain a better understanding of the emissions profile from that source category. The IPCC Guidelines often include higher tier methods that use bottom-up data, and more detailed descriptions of how to use these methods have been developed as part of the IPCC's ongoing work on good practice guidance. States are encouraged to refer to this good practice guidance, as it becomes available, when developing or implementing bottom-up methods for estimating emissions.

Preparing a state-level greenhouse gas inventory is a voluntary activity with no regulatory significance. This is in contrast to the inventories of criteria air pollutants, and the regulation of these pollutants, mandated under the Clean Air Act. Because greenhouse gas emissions are

currently unregulated, greenhouse gas inventories are intended to serve primarily as a prelude to voluntary state-level greenhouse gas reduction plans (i.e., action plans). Consequently, greenhouse gas inventories may be developed using methodologies that involve many more uncertainties and assumptions than would be acceptable for methodologies to estimate emissions of criteria air pollutants.

At the same time, greenhouse gas inventories have much in common with inventories of criteria air pollutants. State officials involved in preparing criteria air pollutant inventories are likely to have a level of expertise and familiarity with inventory methods that would give them a head start in preparing a greenhouse gas inventory. For fossil fuel combustion in particular, many of the data sources for greenhouse gas inventories are the same as those used for criteria air pollutant inventories. Another similarity between GHG inventories and criteria pollutant inventories is that the process must be conducted with due regard for handling of confidential business information (CBI). Some process information (e.g., production characteristics and outputs) is useful for estimating GHG emissions, but is often considered very sensitive by industry, so the inventory effort must be designed to identify, manage, and report CBI with care.

Regardless of the methodologies or estimation techniques a state may decide to use, the key to a sound emissions inventory is documentation of the activity data and emission factors being used. This includes information on their derivation and clear definitions of activities. Any emissions inventory that is not accompanied by sound documentation is unverifiable. Without clear documentation of the methods employed and data used, it will be impossible to refine and improve the accuracy of greenhouse gas inventories. States may also at some point want to compare their inventories with those of other states, or pool statistics in a regional inventory. This can only be done if emissions are estimated using comparable and consistent methods, with data that are understandable and verifiable.

Once a state has estimated greenhouse gas emissions from each source category, the emissions must be summed across all categories. Table I.5-1 is a blank table that states may use for this purpose. To simplify the summation, the table provides for recording of estimates developed in each chapter of this volume. Note that the final column of this table provides for estimating emissions in units of metric tons of carbon equivalent (MTCE), rather than metric tons of carbon dioxide equivalent. Units of MTCE are used because carbon is easier to track than carbon dioxide, since carbon is not always found in the molecular form of carbon dioxide. To convert emissions of CO₂ as measured on a full molecular basis to units of MTCE, a factor of 12/44 is used to convert the mass of CO₂ to the mass of the carbon in CO₂. For other greenhouse gases, the global warming potentials have been calculated for each gas on a full molecular weight basis, relative to the full molecular weight of CO₂. Thus, for consistency, when determining the emissions of other greenhouse gases on a carbon equivalent basis, the same factor of 12/44 is used, in combination with the global warming potential, to convert emissions from the full molecular weights to MTCE.

TABLE I.5-1 SUMMARY TABLE FOR REPORTING EMISSIONS ESTIMATES

SOURCE	GAS	EMISSIONS (short tons, on a full molecular basis)	EMISSIONS (metric tons, on a full molecular basis: short tons) 1.1023)	Mass Ratio of Carbon to Carbon Dioxide	GWP*	EMISSIONS (metric tons of carbon equivalent: metric tons of emissions times 12/44 times GWP)
Fossil Fuel Combustion	CO ₂			12/44	1	
Industrial Sources (non-energy)	CO ₂			12/44	1	
	N ₂ O			12/44	310	
	CF ₄			12/44	6,500	
	C ₂ F ₆			12/44	9,200	
	HFC-23			12/44	11,700	
	SF ₆			12/44	23,900	
	Other high GWP gases			12/44	(see text in chapter 2)	
Natural Gas and Oil Systems	CH ₄			12/44	21	
Coal Mining	CH ₄			12/44	21	
Waste Management	CH ₄			12/44	21	
	CO ₂			12/44	1	
	N ₂ O			12/44	310	
Domesticated Animals	CH ₄			12/44	21	
Manure Management	CH ₄			12/44	21	
Flooded Rice Fields	CH ₄			12/44	21	
Agricultural Soil Management	N ₂ O			12/44	310	
Forest Management and Land Use Change	CO ₂			12/44	1	
Burning of Agricultural Crop Wastes	CH ₄			12/44	21	
	N ₂ O			12/44	310	
Municipal Wastewater	CH ₄			12/44	21	
Mobile Combustion	CH ₄			12/44	21	
	N ₂ O			12/44	310	
Stationary Combustion	CH ₄			12/44	21	
	N ₂ O			12/44	310	
Total Emissions	CO ₂			12/44	1	
	CH ₄			12/44	21	
	N ₂ O			12/44	310	
	CF ₄			12/44	6,500	
	C ₂ F ₆			12/44	9,200	
	HFC-23			12/44	11,700	

*Source: IPCC 1997.

HARMONIZING STATE, NATIONAL, AND INTERNATIONAL INVENTORY METHODS

As noted above, the methodologies presented in this volume to assist states in identifying and estimating their emissions of greenhouse gases have been adapted from Volumes 1-3 of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1997) and the *Greenhouse Gas Emissions and Sinks: 1990-1996* (U.S. EPA, 1998b). In many cases, the methodologies presented are congruent with the IPCC Guidelines; however, for emission sources considered to be major sources in the U.S., the IPCC default methodologies have been expanded. In these cases – energy consumption, forest sinks, and some methane sources – more comprehensive, U.S.-specific methods are provided. While fully consistent with the IPCC Guidelines, these methods are designed to make use of the best information resources available.

Prior to the publication of this volume, states have developed greenhouse gas inventories using the U.S. EPA's *State Workbook: Methodologies for Estimating Greenhouse Gas Emissions* (U.S. EPA 1998a). As noted above, this volume (1) adds two chapters that were not included in the *State Workbook* (Chapters 13 and 14 which cover, respectively, non-CO₂ emissions from mobile sources and from stationary sources), and (2) includes tables which evaluate the accuracy of emission factors and activity levels used to estimate greenhouse gas emissions (these tables are known as "Data Attribute Ranking System" or DARS tables). Figure 1.6-1 presents a ranking of DARS values for all estimation methodologies included in this volume. Values range from 0.28 for indirect N₂O emissions from manure and fertilizer to 0.95 for CH₄ emissions from coal produced from underground mining. Table 1.6-1 presents DARS values for each method by chapter.

This volume also reflects inputs from state energy and environmental officials received on the *State Workbook*, and has been reformatted to conform with the Emission Inventory Improvement Program (EIIP) format. Table I.6-1 presents a comparison of the EIIP methods for estimating greenhouse gas emissions with the methods used in (1) the U.S. greenhouse gas inventory (U.S. EPA 1998b) and (2) the guidelines prepared by the Intergovernmental Panel on Climate Change (IPCC 1997). The U.S. greenhouse gas inventory is prepared each year by the U.S. Environmental Protection Agency, to meet a commitment made by the U.S. as a signatory to the Framework Convention on Climate Change. The IPCC guidelines were developed to provide a uniform methodology to be used by all signatory countries to the Framework Convention when estimating their greenhouse gas emissions. Countries are expected to use the methods in the IPCC guidelines unless they have developed alternative methods of equal or greater accuracy.

In general, where the EIIP methods differ from the methods used in the U.S. greenhouse gas inventory, or the methods recommended in the IPCC guidelines, they differ because the data needed to follow the U.S. or IPCC methods are unavailable at the state level.

**FIGURE I.6-1
COMPARISON OF DARS VALUES FOR ALL METHODOLOGIES**

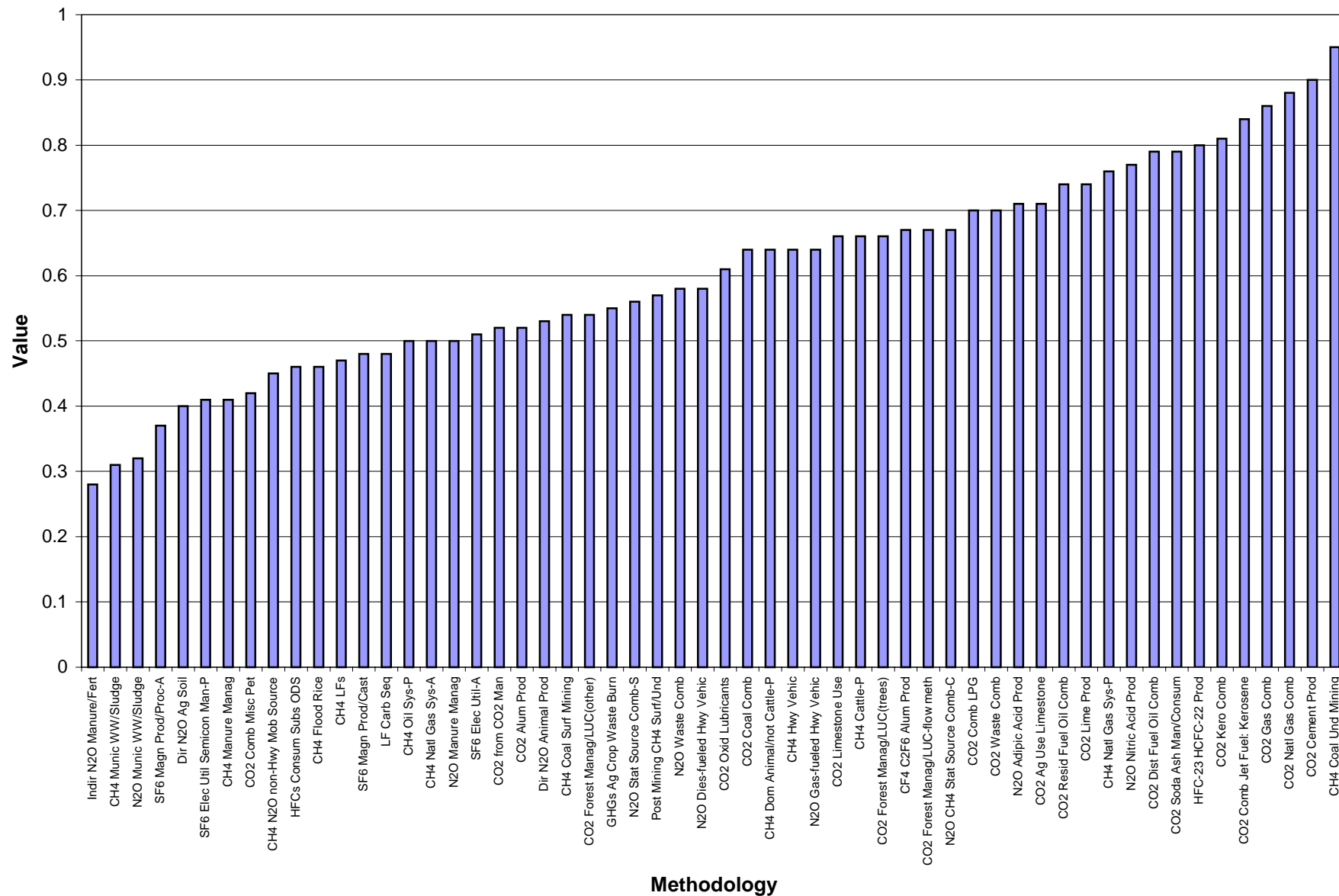


TABLE I.6-2
SUMMARY OF DARS VALUES BY CHAPTER

Chapter	Calculation Method	DARS Value	Chapter	Calculation Method	DARS Value
1	CO ₂ from Combustion of Miscellaneous Petroleum Products	0.42	4	CH ₄ from Coal Produced from Surface Mining	0.54
	CO ₂ from Oxidation of Lubricants	0.61		Post Mining CH ₄ emissions from Surface and Underground Mining	0.57
	CO ₂ from Coal Combustion	0.64		CH ₄ from Coal Produced from Underground Mining	0.95
	CO ₂ from Combustion of Liquefied Petroleum Gas	0.7	5	CH ₄ from Landfills	0.47
	CO ₂ from Residual Fuel Oil Combustion	0.74		Landfill Carbon Sequestration	0.48
	CO ₂ from Distillate Fuel Oil Combustion	0.79		N ₂ O from Waste Combustion	0.58
	CO ₂ from Kerosene Combustion	0.81		CO ₂ from Waste Combustion	0.7
	CO ₂ from Combustion of Jet Fuel: Kerosene Type	0.84	6	CH ₄ from Domestic Animals Other than Cattle (Pref.)	0.64
	CO ₂ from Gasoline Combustion	0.86		CH ₄ from Cattle (Pref.)	0.66
	CO ₂ from Natural Gas Combustion	0.88	7	CH ₄ from Manure Management	0.41
2	SF ₆ from Magnesium Production and Processing (Alt.)	0.37		N ₂ O from Manure Management	0.5
	SF ₆ from Electric Utilities and Semiconductor Manufacturers (Pref.)	0.41	8	CH ₄ from Flooded Rice Fields	0.46
	HFCs from Consumption of Substitutes for Ozone-Depleting Substances	0.46		Indirect N ₂ O from Manure and Fertilizer	0.28
	SF ₆ from Magnesium Production and Casting	0.48	9	Direct N ₂ O from Agricultural Soils	0.4
	SF ₆ from Electric Utilities (Alt.)	0.51		Direct N ₂ O from Animal Production	0.53
	CO ₂ from Carbon Dioxide Manufacture	0.52		CO ₂ from Agricultural Use of Limestone	0.71
	CO ₂ from Aluminum Production	0.52	10	CO ₂ from Forest Management and Land Use Change (other)	0.54
	CO ₂ from Limestone Use	0.66		CO ₂ from Forest Management and Land Use Change (trees)	0.66
	CF ₄ and C ₂ F ₆ from Aluminum Production	0.67		CO ₂ from Forest Management and Land Use Change (flow method)	0.67
	N ₂ O from Adipic Acid Production	0.71	11	GHGs from Burning of Agricultural Crop Wastes	0.55
	CO ₂ from Lime Production	0.74		CH ₄ from Municipal Wastewater and Sludge	0.31
	N ₂ O from Nitric Acid Production	0.77	12	N ₂ O from Municipal Wastewater and Sludge	0.32
	CO ₂ from Soda Ash Manufacture and Consumption	0.79	13	CH ₄ and N ₂ O from Non-Highway Mobile Sources	0.45
	HFC-23 from HCFC-22 Production	0.8		N ₂ O from Diesel-Fueled Highway Vehicles	0.58
	CO ₂ from Cement Production	0.9		CH ₄ from Highway Vehicles	0.64
				N ₂ O from Gasoline-Fueled Highway Vehicles	0.64
3	CH ₄ from Oil Systems (Pref.)	0.5	14	N ₂ O from Stationary Source Combustion (Simple)	0.56
	CH ₄ from Natural Gas Systems (Alt.)	0.5		N ₂ O and CH ₄ from Stationary Source Combustion (Complex)	0.67
	CH ₄ from Natural Gas Systems (Pref.)	0.76			

Table I.6-3 Comparison of Greenhouse Gas Emission Inventory Methods

Gas/Source (Those included in U.S. Inventory)	Section in EIIP Documents	Section in IPCC Guidelines	Differences between EIIP Method and U.S. Inventory Method	Differences between EIIP Method and IPCC Guidelines
CO₂				
Fossil Fuel Combustion	Chapter 1	1.4 and 1.5	EIIP method is analogous to U.S. Inventory method. The same fuels and end-use sectors are identified. Less attention is paid to international bunkers estimation. Interstate (domestic) bunkers are included, whereas U.S. Inventory excludes international bunkers. Electricity imports/exports are included, unlike in U.S. Inventory.	EIIP method is fully consistent with a detailed Tier 1 approach as outlined in the IPCC guidelines.
Natural Gas Flaring	(not addressed)	1.4, 1.5, and 1.8	The U.S. Inventory includes these emissions based on data on the amount of natural gas flared, as provided by the Energy Information Administration.	Not addressed
Cement Manufacture	Chapter 2	2.3	EIIP method is analogous to U.S. method and employs identical emission factors and other coefficients.	EIIP method is fully consistent with the IPCC guidelines.
Lime Manufacture	Chapter 2	2.4	EIIP method is analogous to U.S. method, but the U.S. inventory addresses dolomitic lime separately whereas the EIIP method does not. Also, the U.S. Inventory does not address the exclusion in the U.S.G.S. data of lime produced by pulp and paper mills, carbide plants, and water treatment plants.	EIIP method is consistent with the IPCC guidelines, although the IPCC guidelines address dolomitic lime separately, and the EIIP method does not.
Limestone and Dolomite Use	Chapter 2	2.5	EIIP method is analogous to U.S. method.	EIIP method is consistent with the IPCC guidelines; however, the EIIP method specifies that liming of soils should be accounted for separately under agricultural soils, rather than under land use change and forestry, as specified by the IPCC.
Soda Ash Manufacture and Consumption	Chapter 2	2.6	The EIIP method is consistent with the U.S. method, although only Wyoming and California produce soda ash, and because of the process used, theoretically no CO ₂ emissions are generated by production in California.	EIIP method is fully consistent with the IPCC guidelines.
Carbon Dioxide Manufacture	Chapter 2	(not addressed)	The EIIP method is consistent with the U.S. Inventory method.	This source is not addressed in the IPCC guidelines.
Land-Use Change and Forestry (source or sink)	Chapter 10	5	The two methods are consistent with the exception that the EIIP method does not account for wood in products or landfills. The timing and date of the forest inventory used may also differ between the EIIP and U.S. Inventory methods. The national inventory is compiled using a U.S.FS model which is not available to states. Furthermore, regional estimates of activity data may differ between the EIIP and U.S. Inventory methods. The EIIP method provides default data which the national inventory does not use.	The EIIP approach is consistent with the IPCC guidelines. The IPCC provides detailed guidelines for the flow approach. However, the IPCC suggests using the stock method if a country has good land use data. The IPCC and EIIP methods do not count wood in products or landfills; the U.S. Inventory does.
Biomass (Wood and Ethanol)	(not addressed)	1.4.3 and 1.5	The EIIP method does not estimate carbon dioxide emissions from this source because the carbon is assumed to be recycled in new biomass growth on a sustainable basis. These emissions are estimated for information purposes in the U.S. Inventory.	The IPCC method recommends including biomass fuels for information purposes only; if biomass is not grown sustainably, that should be noted under Land Use Change and Forestry.

Table I.6-3 Comparison of Greenhouse Gas Emission Inventory Methods

Gas/Source (Those included in U.S. Inventory)	Section in EIIP Documents	Section in IPCC Guidelines	Differences between EIIP Method and U.S. Inventory Method	Differences between EIIP Method and IPCC Guidelines
Aluminum Production	Chapter 2	2.13.5	In the U.S. Inventory method, carbon dioxide emissions from this source are not counted separately because the carbon is already accounted for under fossil fuel combustion (non-fuel uses of petroleum coke). In the EIIP method, carbon dioxide emissions from this source are only counted separately if the data used to estimate emissions from fossil fuel combustion do not include petroleum coke.	EIIP method is consistent with the IPCC guidelines. However, the IPCC guidelines provide emission factors for both Soderberg process plants (1.8 tons CO ₂ /ton Al) and for prebaked anode plants (1.5 tons CO ₂ /ton Al); the EIIP method provides only the emission factor for prebaked anode plants, because that is the technology employed by most U.S. aluminum producers.
Iron and Steel Production	(not addressed)	2.13.3	The EIIP method does not address this area. In the U.S. Inventory, carbon dioxide emissions from this source are not counted towards national emission totals, but are estimated for information purposes. Emissions from coke, the primary source of emissions, are accounted for in the U.S. Inventory under non-fuel uses of fossil fuels.	The EIIP method does not address this area. The IPCC guidelines describe how to estimate these emissions but cautions that care should be taken not to double count emissions.
Ammonia Manufacture	(not addressed)	2.8	The EIIP method does not address this area. In the U.S. Inventory, carbon dioxide emissions from this source are not counted toward national emission totals, but are estimated for information purposes. Natural gas feedstocks are the primary source of emissions; they are accounted for in the U.S. Inventory under non-fuel uses of fossil fuels.	The EIIP method does not address this area. The IPCC guidelines describe how to estimate these emissions but also note that emissions depend on the amount of gas or oil used in the process, and assume that all carbon in the gas or oil will be emitted to air.
Ferroalloy Production	(not addressed)	2.13.4	Same as for Iron and Steel Production, above.	Same as for Iron and Steel Production, above.
CH₄				
Stationary (combustion) sources	Chapter 14	1.4.2 and 1.5.2	The EIIP method is completely consistent with the national method.	The EIIP method corresponds to the IPCC Tier 2 methodology.
Mobile (combustion) sources	Chapter 13	1.4.2 and 1.5.3	The EIIP method is identical to the national method.	The EIIP method is identical to the IPCC Tier 1 method.
Coal Mining	Chapter 4	1.7	The EIIP method is completely consistent with the national method.	The EIIP method corresponds to the IPCC Tier 2 method.
Natural Gas Systems	Chapter 3	1.8	The U.S. inventory method involves estimating emissions from the four stages of natural gas systems (production through distribution), whereas the EIIP preferred method provides for estimating emissions based only on gas production and consumption. The EIIP method presents a simplified version of the U.S. inventory method under "Alternative Methodologies;" this alternative method uses data on elements of the natural gas system infrastructure (e.g., number of wells).	The EIIP preferred method is identical to the IPCC Tier 1 method. The EIIP alternative method is a form of the rigorous source-specific evaluation approach outlined as the IPCC Tier 3 method.
Petroleum Systems	Chapter 3	1.8	The U.S. inventory uses a complex method involving estimating emissions from various stages of the oil production process, whereas the EIIP preferred method provides for estimating emissions based only on oil production, oil tankered, and oil refined.	The EIIP method is simpler than the IPCC method. The EIIP method multiplies oil consumption by a default emission factor for methane emissions throughout the petroleum system. The IPCC method separates activity data into two stages (with separate emission factors for each): (1) production, and (2) transportation and distribution.

Table I.6-3 Comparison of Greenhouse Gas Emission Inventory Methods

Gas/Source (Those included in U.S. Inventory)	Section in EIIP Documents	Section in IPCC Guidelines	Differences between EIIP Method and U.S. Inventory Method	Differences between EIIP Method and IPCC Guidelines
Petrochemical Production	(not addressed)	2.12	The EIIP method does not identify petrochemical production as a source of methane.	Not addressed
Silicon Carbide Production	(not addressed)	2.11.1	The EIIP method does not identify silicon carbide production as a source of methane.	Not addressed
Enteric Fermentation	Chapter 6	4.2	The EIIP method is identical to the national inventory method.	The EIIP method provides the IPCC methodology as an alternative to the default methodology. The two methodologies are conceptually similar, but the IPCC method allows for a wider array of animal types. However, the categorization and calculations required by the IPCC methodology make it more difficult to use. The IPCC Guidelines present enteric fermentation and manure management in the same section.
Manure Management	Chapter 7	4.2	The EIIP method is identical to the national inventory method.	EIIP method is similar and conceptually the same as the Tier 2 IPCC method, except for the basis for computing volatile solids: the EIIP method uses animal mass, whereas the IPCC method uses animal intake.
Rice Cultivation	Chapter 8	4.3	The EIIP method is identical to the national inventory method.	The EIIP method is identical to the IPCC method.
Agricultural Residue Burning	Chapter 11	4.4	The EIIP method is identical to the national inventory method except that the national inventory also accounts for barley, corn, soybeans, and peanuts, in addition to wheat, rice, and sugarcane.	The EIIP method is identical to the IPCC method.
Landfills	Chapter 5	6.2	The EIIP method is derived from the national inventory method; both methods are conceptually similar. The national inventory uses a computer model to calculate emissions based on landfill population data. The EIIP method makes it possible to calculate landfill emissions without this computer model.	The EIIP method is based on empirical gas measurements at US landfills, and employs a statistical approach. The IPCC guidelines present a conceptually similar method, albeit with a different functional form.
Wastewater Treatment	Chapter 12	6.3	The EIIP method is identical to the national inventory method, but includes guidelines for estimating emissions from sludge, which the national inventory omits.	The EIIP method is identical to the IPCC method. The IPCC includes guidelines for estimating emissions from industrial wastewater; the EIIP method includes these emissions in the alternate methodology.
N₂O				
Stationary (combustion) sources	Chapter 14	1.4.2 and 1.5.2	The EIIP method is completely consistent with the national method.	The EIIP method is consistent with the IPCC Guidelines and corresponds to the Tier 2 methodology.
Mobile (combustion) sources	Chapter 13	1.4.2 and 1.5.3	The EIIP method is identical to the national method.	The EIIP method is identical to the IPCC method.
Adipic Acid	Chapter 2	2.1	The method and emission factor in the EIIP method are consistent with those in the U.S. Inventory.	The EIIP method is fully consistent with the IPCC method.
Nitric Acid	Chapter 2	2.9	The method and emission factor in the EIIP method are consistent with those in the U.S. Inventory. However, that the data source suggested may not provide state level data on nitric acid production.	The EIIP method is fully consistent with the IPCC method.
Manure Management	Chapter 7	4.2	EIIP method is consistent with U.S. Inventory method.	The EIIP method is fully consistent with the IPCC method.

Table I.6-3 Comparison of Greenhouse Gas Emission Inventory Methods

Gas/Source (Those included in U.S. Inventory)	Section in EIIP Documents	Section in IPCC Guidelines	Differences between EIIP Method and U.S. Inventory Method	Differences between EIIP Method and IPCC Guidelines
Agricultural Soil Management	Chapter 9	4.5	The EIIP method is identical to the former U.S. Inventory method for calculating emissions from fertilizer use. To conform with the current national inventory, the following sources of nitrous oxide emissions are being added to the EIIP method: production of nitrogen-fixing crops, the incorporation of crop residues into soil, cultivation of histosols, direct deposition of animal wastes to the land, and indirect pathways.	The EIIP method is identical to the IPCC method for calculating emissions from fertilizer use. The methods being added are identical to both the U.S. Inventory and the IPCC methods.
Agricultural Residue Burning	Chapter 11	4.4	The EIIP method is identical to the national inventory method except that the national inventory now accounts for barley, corn, soybeans, and peanuts, in addition to wheat, rice, and sugarcane.	The EIIP method is identical to the IPCC method.
Human Sewage	Chapter 12	6.4	EIIP method is consistent with U.S. Inventory and IPCC methods	EIIP method is consistent with U.S. Inventory and IPCC methods
Waste Combustion	Chapter 5	6.5	The two methods are conceptually the same but use different emission factors. The EIIP method uses emission factors from the EPA report on greenhouse gas emissions from municipal waste. The national inventory uses factors provided in the EPA report <i>Compilation of Air Pollution Emission Factors (AP-42)</i> .	The emission factor used in the EIIP method was obtained by averaging the emission factors in the IPCC Reference Manual.
HFCs, PFCs, and SF₆				
Substitution of Ozone Depleting Substances	Chapter 2	2.17	EIIP method is based on national method.	EIIP method is based on interpolating national emission estimate (developed according to IPCC methods) to states.
Aluminum Production	Chapter 2	2.13.6	The method used for the U.S. Inventory is currently being revised to account for activities under EPA's voluntary program for aluminum producers. The EIIP method is consistent with the method and emission factors employed in previous U.S. inventories.	EIIP method is consistent with the IPCC guidelines; however, EIIP method does not recommend estimating emission by technology type as is done in the IPCC guidelines.
HCFC-22 Production	Chapter 2	2.16	The two methods are conceptually the same but use slightly different emission factors. The default emission factor per unit of output presented in the EIIP method (2% on a mass basis) is consistent with that in the U.S. Inventory method.	The IPCC guidelines suggests an emission factor of 4% on a mass basis, citing earlier EPA studies. EIIP method is consistent with the guidelines, but appropriately suggests a more recent emission factor (2%).
Electrical Transmission and Distribution	Chapter 2	2.17.4.8	The EIIP method suggests assuming consumption equals emissions, which does not account for changes in the total SF ₆ stock in electrical equipment, but is reasonable given likely data limitations.	The IPCC guidelines suggest applying a 1% per year leak rate over a 30 year equipment lifetime to the total stock of SF ₆ in electrical equipment.
Magnesium Production and Processing	Chapter 2	2.13.8	The EIIP method suggests assuming consumption equals emissions, which is reasonable because magnesium producers generally do not maintain stocks of the gas.	The EIIP method conforms to the IPCC guidelines, which suggest estimating emissions as equal to consumption.

OVERVIEW OF VOLUME VIII

This volume contains 14 chapters, each pertaining to a particular anthropogenic activity that results in emissions of greenhouse gases. This volume is organized as follows:

- Chapter 1:** Carbon Dioxide Emissions from Combustion of Fossil Fuels
- Chapter 2:** Non-Energy Greenhouse Gas Emissions from Industrial Processes
- Chapter 3:** Methane Emissions from Natural Gas and Oil Systems
- Chapter 4:** Methane Emissions from Coal Mining
- Chapter 5:** Greenhouse Gas Emissions from Municipal Waste Management
- Chapter 6:** Methane Emissions from Domesticated Animals
- Chapter 7:** Greenhouse Gas Emissions from Manure Management
- Chapter 8:** Methane Emissions from Flooded Rice Fields
- Chapter 9:** Greenhouse Gas Emissions from Agricultural Soils
- Chapter 10:** CO₂ Emissions and Sinks from Forest Management and Land-Use Change
- Chapter 11:** Greenhouse Gas Emissions from Burning of Agricultural Crop Wastes
- Chapter 12:** Greenhouse Gas Emissions from Municipal Wastewater
- Chapter 13:** Methane and Nitrous Oxide Emissions from Mobile Combustion
- Chapter 14:** Methane and Nitrous Oxide Emissions from Stationary Combustion

These chapters are also available on the Internet at http://www.epa.gov/ttn/chief/eiip/eiig_ghg.htm.

It is recommended each state complete all chapters applicable to the state.¹³ While all chapters are important, states should spend the greatest amount of time on Chapter 1, because CO₂ emissions from fossil fuel combustion are likely to be the single greatest source of greenhouse gas emissions. After Chapter 1, states should focus on Chapters 2 through 9, because these chapters address the next largest sources of greenhouse gas emissions. Note that many agricultural and forestry activities emit greenhouse gases; these activities are addressed in several chapters. Table I.7-1 summarizes the agricultural and forestry activities associated with emissions of CO₂, CH₄, and N₂O, and provides a roadmap indicating the chapter in which each activity is addressed.

Each chapter suggests sources for the data that are required to complete the emissions calculations. In some cases, default values are provided in the event that state information is not available. However, in all cases, state information should be used where available.

¹³ Most states will not need to complete Chapters 4 and 8, because coal is mined in only thirteen states and rice is produced in only seven.

Table I.7-1. GHG Emissions from the Agricultural and Forest Sectors

A check indicates emissions may be significant.

Activity	Associated GHG Emissions and Chapter where these Emissions are Addressed					
	CO ₂	Chapter	CH ₄	Chapter	N ₂ O	Chapter
Energy (Farm Equipment)	✓	1	✓	13	✓	13
Animal Production: Enteric Fermentation			✓	6		
Animal Production: Manure Management						
Solid Storage			✓	7	✓	7
Drylot			✓	7	✓	7
Deep Pit Stacks			✓	7	✓	7
Litter			✓	7	✓	7
Liquids/Slurry			✓	7	✓	7
Anaerobic Lagoon			✓	7	✓	7
Pit Storage			✓	7	✓	7
Periodic land application of solids from above management practices					✓	Not included ^a
Pasture/Range (deposited on soil)			✓	7	✓	9
Paddock (deposited on soil)			✓	7	✓	9
Daily Spread (applied to soil)			✓	7	✓	9
Animal Production: Nitrogen Excretion (indirect emissions)					✓	9
Cropping Practices						
Rice Cultivation			✓	8		
Commercial Synthetic Fertilizer Application					✓	9
Commercial Organic Fertilizer Application					✓	9
Incorporation of Crop Residues into the Soil					✓	9
Production of Nitrogen-fixing Crops					✓	9
Liming of Soils	✓	9				
Cultivation of High Organic Content Soils (histosols)	✓	Not included ^a			✓	9
Cultivation of Mineral Soils	✓	Not included ^a				
Changes in Agricultural Management Practices (e.g., tillage, erosion control)	✓	Not included ^a				
Forest and Land Use Change						
Forest and Grassland Conversion	✓	10				
Abandonment of Managed Lands	✓	10				
Changes in Forests and Woody Biomass Stocks	✓	10				
Agricultural Residue Burning			✓	11	✓	11

^a Emissions may be significant, but methods for estimating GHG emissions from these sources are not included in the EIIP chapters.

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